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The Advanced Tangentially Fired Combustion Techniques for the Reduction of Nitrogen Oxides (NO_X) Emissions From Coal-Fired Boilers Demonstration Project: A DOE Assessment

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Disclaimer

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Executive Summary

This document serves as a DOE post-project assessment of a project in Round 2 of the Department of Energy's Clean Coal Technology (CCT) Program: *Advanced Tangentially Fired Combustion Techniques for the Reduction of Nitrogen Oxides (NO_X) Emissions From Coal-Fired Boilers Demonstration Project*. In September 1990, Southern Company Services entered into an agreement to conduct the study, with Gulf Power Company providing the 180 megawatt electric (MWe) host site and ABB C-E Services Inc. providing the technology to be demonstrated.

This project was undertaken to evaluate the nitrogen oxides (NO_X) reduction potential of several variations of the Low NO_X Concentric Firing System (LNCFS™) when applied to tangentially fired (T-fired) boilers. The project consisted of replacing the existing coal and air nozzles with new nozzles and adding overfire air. Three versions of the LNCFS™ system were tested: Level I consisted of new coal nozzles and close-coupled overfire air; Level II used the same burners but separated the overfire air; and Level III used both close-coupled and separated overfire air. The performance objectives were as follows:

- To determine the short-term and long-term NO_X emissions reduction capabilities and impact on unit performance of the low-NO_X combustion technologies of LNCFS™ Levels I, II, and III when implemented in a stepwise manner on a T-fired boiler operating under normal dispatch conditions. The NO_X reduction objective was 50 percent.

- To compare the performance and cost effectiveness of these technologies.

- To determine the relationship between operating parameters (e.g., unit load, percent overfire air) and NO_X emissions and other unit performance indicators, such as unburned carbon, carbon monoxide (CO) level, and air toxics.

All goals were met in the demonstration project, which was conducted at Gulf Power's Plant Lansing Smith Unit No. 2 (rated at 180 MWe, but capable of operation at 200 MWe). In the load range of 50 to 100 percent capacity, NO_X removal ranged from 37 percent for Levels I and II to 45 percent for Level III. At loads below 50 percent, NO_X reduction was lower. Relatively few problems were encountered with the LNCFS™ system. Carbon content of the ash was essentially unaffected, as were air toxics emissions and electrostatic precipitator (ESP) operation. Furnace fouling was reduced somewhat, although backpass fouling increased slightly. Unit efficiency increased slightly for Level I and decreased slightly for Levels II and III.

Estimated costs for installing the LNCFS™ system vary from $3 to $15 per kilowatt (kW) for Level I to $10 to $25/kW for Levels II and III. The LNCFS™ system is an economical technology for reducing NO_X emissions from T-fired boilers, particularly base-load units. This CCT project represents a successful commercial demonstration of the LNCFS™ technology. The unit on which the LNCFS™ system was demonstrated is a commercial boiler, operating under real-world dispatch conditions. With proper tuning and adjustment, the LNCFS™ system is applicable to a wide range of T-fired boilers. Indeed, the LNCFS™ technology has been successfully commercialized, with about 42,000 MWe of capacity currently in operation.

I Introduction

The goal of the U.S. Department of Energy (DOE) Clean Coal Technology (CCT) Program is to furnish the energy marketplace with advanced, more efficient, and environmentally friendly coal utilization technologies through demonstration projects. The purpose is to establish the commercial feasibility of the most promising advanced coal technologies that have already achieved proof-of-concept testing.

This document serves as a DOE post-project assessment of the 180 megawatt electric (MWe) *Demonstration of Advanced Tangentially Fired Combustion Techniques for the Reduction of Nitrogen Oxide Emissions From Coal-Fired Boilers*. On September 20, 1990, DOE and Southern Company Services (SCS) entered into an agreement to demonstrate the Low Nitrogen Oxide (NO_X) Concentric Firing System (LNCFS™) Levels I, II, and III and Low NO_X Bulk Furnace Staging (LNBFS) on a tangentially fired (T-fired) furnace burning coal. Cosponsors of this project with DOE were SCS and EPRI (formerly the Electric Power Research Institute). ABB C-E Services Inc. (ABB/CE), the technology supplier, shared in cost of the LNCFS™ retrofits.

The test effort began in May 1991 and ended in December 1992. The project was completed in March 1994. This independent evaluation is based primarily on the 1994 Final Report and Key Project Findings, prepared by Energy Technologies Enterprises Corp. This report as well as other documents used in the evaluation are listed in the bibliography.

II Technical and Environmental Assessment

II.A Promise of the Technology

When this project was selected in the second round of the CCT Program, the participants recognized the importance of demonstrating an economical low-NO_X combustion technology that could be retrofitted to T-fired boilers to allow them to meet the requirements of the Clean Air Act Amendments (CAAA) of 1990. The LNCFS™ demonstrated in this project was such a technology.

Two major portions of the CAAA of 1990 relevant to emission controls on power plants are Title I and Title IV. Title I establishes National Ambient Air Quality Standards (NAAQS) for six criteria pollutants: ozone, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon dioxide (CO_2), lead, and particulates. Title IV, often referred to as the Acid Rain Program, addresses controls for specific types of boilers, including coal-fired units. The CAAA authorized the U.S. Environmental Protection Agency (EPA) to establish emissions standards for a number of atmospheric pollutants, and to revise and expand the standards for emissions of SO_2 and NO_X. The CAAA mandates updating of the emissions standards every 5 years.

Title IV imposes a two-phase NO_X control strategy. Phase I, which had an implementation deadline of January 1, 1996, established regulations for 256 Group 1 boilers: dry-bottom, wall-fired, and T-fired boilers. In Phase II, which requires compliance by January 1, 2000, lower emission limits are set for Group 1 boilers, and limits are set for 145 Group 2 boilers, which include cell-burners, cyclones, wet-bottom wall-fired boilers, and other types of coal-fired boilers. In addition, another 607 wall-fired and T-fired boilers must meet the applicable Phase II limits. The emission limits under Title IV, promulgated in February 1998, are shown in Table 1.

When NO_X and volatile organic compounds (VOCs) enter the atmosphere, they react in the presence of sunlight to form ground-level ozone, which is the major ingredient of smog. The federal Title I NO_X requirements are: (1) existing major stationary sources must apply reasonably available control technologies (RACT), (2) new or modified major stationary sources must offset their new emissions and install controls representing the best available control technology (BACT), and (3) each state must include ozone control in its State Implementation Plan (SIP).

The current NAAQS for ozone is 0.08 ppm (8-hour average). Many large- and medium-sized urban areas do not meet this standard and are classified as “nonattainment.” A large number of power plants are within these nonattainment areas. This nonattainment status is attributable not only to NO_X emissions in a given locality, but also to significant amounts of NO_X and VOCs transported by winds over a relatively wide geographical region.

To address regional pollutant transport, EPA issued a rule in September 1998 governing NO_X emissions from electric power plants and other large stationary boilers in an area consisting of 22 Eastern states and the District of Columbia. To meet the ground-level ozone NAAQS in this area, the rule specifies an average NO_X emission rate for electric power plants of 0.15 lb/10^6 Btu during the five-month (May through September) “summer” ozone season. The rule requires emission reduction measures to be in place by May 1, 2003.

Table 1. Title IV NO_X Emissions Limits
($lb/10^6$ Btu)

	Phase I	Phase II
Implementation Deadline	January 1, 1996	January 1, 2000
Group 1 Boilers		
Dry Bottom Wall-Fired	0.50	0.46
T-Fired	0.45	0.40
Group 2 Boilers		
Wet Bottom Wall-Fired > 65 MWe	NA	0.84
Cyclone-Fired > 155 MWe	NA	0.86
Vertically Fired	NA	0.80
Cell Burner	NA	0.68
Fluidized Bed	NA	Exempt
Stoker	NA	Exempt

NA = not applicable

EPA’s rule does not mandate which sources must reduce pollution. States can meet the requirements of this rule by reducing emissions from the sources they choose. However, utilities and large non-utility point sources will be the most likely targets for NO_X reductions.

The technologies typically used in utility boilers for NO_X reduction, which have generally proven adequate to meet Title IV emissions requirements, are low NO_X burners (LNBs), overfire air (OFA), or LNBs in combination with OFA. The LNCFS™ systems demonstrated in this project are variations of OFA applied to T-fired boilers. LNCFS™ includes other firing characteristics in addition to OFA, including offset air and a different coal nozzle design. The lower NO_X target levels being considered may force utilities subject to the most stringent requirements to install LNBs, OFA, or both combined with selective catalytic reduction (SCR).

Because several variations of the LNCFS™ technology were available, it was important to test all these variations on the same unit so that direct comparisons could be made. It was also important that the testing be conducted under normal dispatch operating conditions so that the results would represent a real-world situation.

II.B Technology Description

The main technology demonstrated in this project is LNCFS™. Figure 1 is a schematic of the process. Three variations of the LNCFS™ system were tested, as shown in Figure 2. A fourth firing variation, Low-NO_X Bulk Furnace Staging (LNBFS), was also briefly tested. The LNCFS™ system was specifically developed for retrofitting to T-fired furnaces. The major components of the LNCFS™ system are:

- Overfire air,
- Offset auxiliary air, and
- Flame-attachment coal nozzle tips.

II.B.1 Overfire Air (OFA)

OFA means air that is introduced into the furnace above the top coal nozzle. Two types of OFA are used the LNCFS™ technology. Close-coupled overfire air (CCOFA) is OFA that is introduced immediately above the top coal nozzle using the main windbox. Separated overfire air (SOFA) is OFA that is introduced through a windbox separated from the main windbox supplying the bulk of the combustion air.

II.B.2 Offset Auxiliary Air

Offset air refers to air introduced between the coal nozzles. This air is injected through concentric auxiliary nozzle tips that are installed on the air nozzles in the main windbox. The angle of these nozzles can be adjusted both horizontally (yaw) and vertically (pitch). In general, these nozzles are adjusted to direct the air toward the furnace walls to reduce fouling and to produce an oxidizing environment along the water walls. This minimizes the potential for corrosion, and produces two concentric circular combustion regions. Most of the coal is contained in the fuel-rich inner zone, which is surrounded by a fuel-lean outer zone that contains combustion air. The size of the outer zone can be varied by adjusting the yaw and pitch of the offset air nozzles.

II.B.3 Flame-Attachment Nozzle Tips

Flame-attachment tips are installed on the coal nozzles to stabilize and ignite the coal stream close to the nozzles. This devolatilizes the coal as quickly as possible, and releases the nitrogen in the fuel in an oxygen-poor region of the flame. This helps minimize NO_X formation from the nitrogen in the fuel.

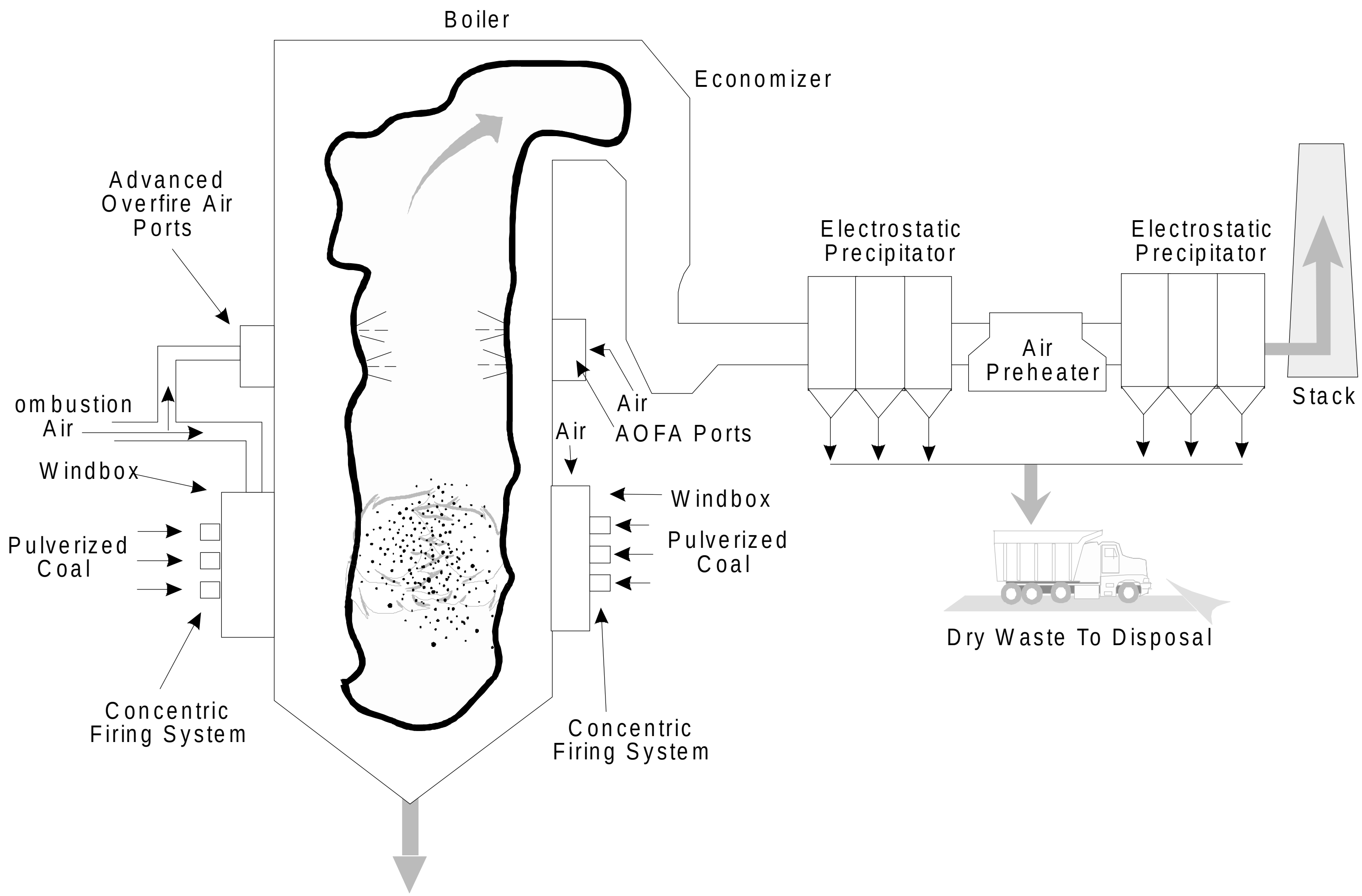

Figure 1. Flow Diagram Showing Major components of Tangentially Fired Combustion Technology System Demonstrated at Unit No. 2 of Plant Lansing Smith

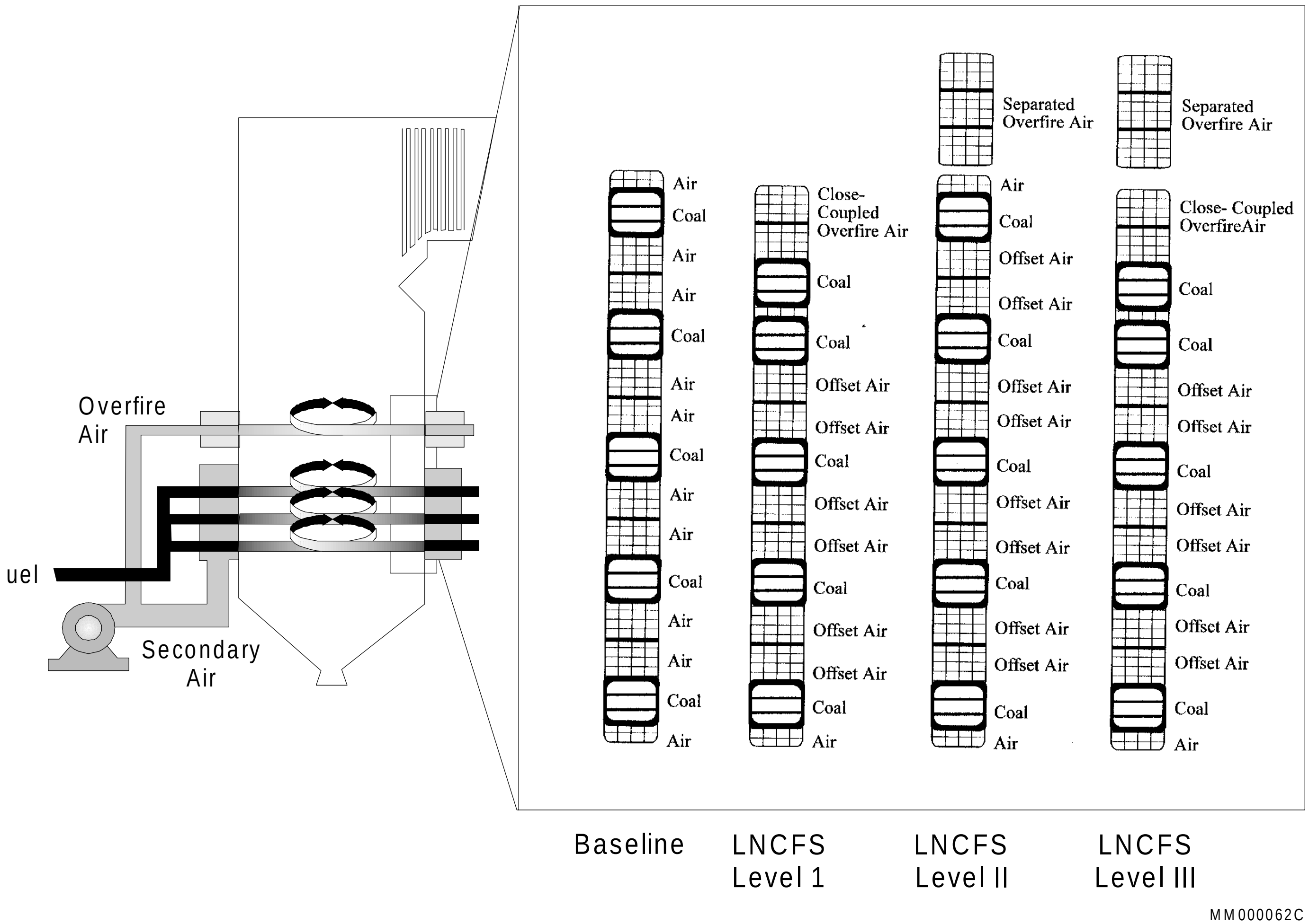

Figure 2. Comparison of Tangentially Fired Combustion Systems

II.C Technologies Demonstrated

Four low-NO_X combustion technologies were tested: LNBFS and three variations of the LNCFS™ system — LNCFS™ Level I, LNCFS™ Level II, and LNCFS™ Level III. LNBFS consists of adding SOFA to the boiler without adding the offset air nozzles that are included in the LNCFS™ system. The three levels of LNCFS™ technology differ from each other as follows:

- LNCFS™ Level I includes CCOFA but does not include SOFA. CCOFA is integrated directly into the existing windbox by exchanging the locations of the top coal and air nozzles. LNCFS™ I is the easiest and cheapest to install, since it does not require the addition of the SOFA windbox.

- LNCFS™ Level II consists of adding a SOFA system to the furnace while maintaining the original arrangement of coal and air nozzles. Thus, it includes SOFA but does not include CCOFA. Because of the need for the SOFA windbox, LNCFS™ II is more expensive than LNCFS™ I. Also, depending on the furnace size and configuration, it may be difficult to install the SOFA windbox on some furnaces.

- LNCFS™ Level III is a combination of LNCFS™ Level I and LNCFS™ Level II in that it includes both CCOFA as in LNCFS™ Level I and also SOFA as in LNCFS™ Level II. LNCFS™ Level III is only slightly more expensive than LNCFS™ Level II.

Because of the larger than average windbox height at the Smith No. 2 plant, the CCOFA system was designed with a cross-section area approximately 20 percent larger than would be used for a typical LNCFS™ III installation. The air supply ductwork for the SOFA was taken off from the secondary air duct and routed to the corners of the furnace above the existing windbox. Dampers were installed downstream from the takeoff in the secondary air duct so that the SOFA system could be operated at a higher pressure than the windbox.

Automatic dampers controlled the air flow rate to each OFA nozzle. The yaw on each SOFA nozzle had to be adjusted manually, but the three SOFA nozzles tilted in unison through controls tied to the tilting of the main nozzles in the secondary windbox. The SOFA system was designed for about 20 to 25 percent of the total air flow. In the LNCFS™ Level III configuration, the SOFA and CCOFA systems together accounted for 30 to 40 percent of the total air flow to the boiler. This is at the upper end of the OFA rate for ABB/CE low-NO_X systems.

The unit was equipped with a continuous emission monitoring system (CEM), a data acquisition system, gas sampling ports, coal and ash sampling devices, heat flux measurements, and an acoustic gas temperature monitoring system at the furnace outlet plane.

II.D Project Objectives/Results

The main objectives of this project were:

- To determine the short- and long-term NO_X emissions reduction capabilities and impact on unit performance of the low-NO_X combustion technologies, LNBFS and LNCFS™ Levels I, II, and III, implemented in a stepwise manner on a T-fired boiler operating under normal dispatch operating conditions. Anticipated NO_X reductions were in the 50 to 60 percent range.

- To compare the performance and cost effectiveness of these technologies.

- To determine the relationship between operating parameters (e.g., unit load, percent OFA) and NO_X emissions and other unit performance indicators, such as unburned carbon, carbon monoxide level, and air toxics.

Both short- and long-term tests were performed during this project. Short-term tests typically lasted only a few hours, whereas long-term tests generally lasted for a number of days. Short- and long-term NO_X emissions refer to NO_X emissions measured during short- and long-term tests, respectively.

The objectives of the short- and long-term tests were different. Short-term testing was performed to determine the effect of process variables on the NO_X emission rate and unit performance. Therefore, during a short-term test, operating conditions were kept as constant as possible, and the test lasted only long enough to get the required data. The purpose of long-term testing, however, was to assess performance of the unit under normal operating conditions, including load changes, and tests typically lasted for a period of weeks.

The order of testing of the four technologies was LNCFS™ Level II, LNBFS, LNCFS™ Level III, and LNCFS™ Level I. This order of testing was dictated by the particular configuration of each technology and the need to make retrofitting as simple as possible. LNCFS™ Level II was retrofitted and tested first. Retrofitting consisted of replacing all the air nozzles and coal nozzles and tips and adding SOFA. The SOFA system contained three sets of air nozzles. Following LNCFS™ Level II testing, LNBFS was briefly tested by setting the offset air nozzles to be in line with the coal nozzles.

The unit was then retrofitted for LNCFS™ Level III by installing CCOFA. This was accomplished by replacing the top coal and two auxiliary air nozzles with one stationary auxiliary air, one coal, and two CCOFA nozzles. After testing LNCFS™ Level III, LNCFS™ Level I was simulated by closing the SOFA dampers, with no additional equipment modifications being made. The following sections discuss the results of baseline testing and testing of the four low-NO_X technologies.

II.D.1 Results of Baseline Testing

Baseline data were collected before the low-NO_X technologies were retrofitted to the unit. The average long-term NO_X emissions level at full load (180 to 200 MWe) was 0.63 lb/10^6 Btu. This NO_X level does not reflect a well-tuned burner system nor optimized boiler performance, but rather normal operations. (The boiler operation was not tuned prior to the baseline tests because real-world conditions were desired.) The NO_X level was relatively constant over the load range of 100 to 200 MWe, but was slightly lower at reduced load, decreasing to about 0.56 lb/10^6 Btu at 75 MWe. Most NO_X readings were within ±0.1 lb/10^6 Btu of the mean at a given load.

Besides the NO_X level, the most important unit performance parameters likely to be affected by low-NO_X technologies are carbon monoxide (CO) level, oxygen level, fly ash, loss on ignition (LOI), furnace slagging, and steam outlet temperature. The values of these parameters during the baseline testing are discussed below.

At full load, oxygen in the flue gas varied between 2.7 and 5.0 percent and averaged 3.7 percent. (The lower limit was set by the need to maintain a low CO level, and the upper limit was set by the capacity limitations of the forced-air draft fan.) Because there was no CO monitor reading in the control room, the oxygen level in the flue gas was set at a safe level to ensure that CO would be below the maximum operating limit of 100 ppm. There was no attempt to minimize oxygen level. Also, the burner tilt mechanisms were not operational, and the burners were set at a horizontal position. During baseline testing, CO emissions remained below 20 ppm.

The effect of oxygen concentration on NO_X level varied with the load during baseline testing. As shown in Table 2, an increase of 1 percent in oxygen concentration caused NO_X emissions to increase by 50 ppm at a boiler load of 180 MWe, but the corresponding NO_X increase was only 33 ppm at 70 MWe.

Table 2. Effect of Flue Gas Oxygen Level on NO_X Emissions

Load, MWe	ppm NO_X Increase per 1 percent Increase in Oxygen Concentration in Flue Gas
180	50
115	40
70	33

During baseline testing, the LOI of the fly ash was 4.8 percent at full load and 4.5 percent at low loads. During this period, the boiler experienced medium slagging. Coal distribution to the four corners of the furnace was not uniform, varying from 18 to 30 percent of the total for each corner; the designed distribution was 22.5 to 27.5 percent to each corner.

The superheater outlet temperature was maintained at 1,000 ^{o}F over the load range, but the reheat outlet temperature was below the design level by 60 to 70 ^{o}F at 100 MWe. This was caused by the removal of the reheat surface in the 1970s, when the type of coal feed was changed. The reheat temperatures observed during baseline testing, rather than design temperatures, were used as the basis for judging the effect of the LNCFS^{TM} technologies on the boiler. No constraints were placed on boiler operations by the ESPs.

In the following discussion of testing results, short-term NO_X emissions refer to data collected during short-term tests, and long-term NO_X emissions refer to data collected during long-term tests.

II.D.2 Results of LNCFS^{TM} Level II Testing

LNCFS^{TM} Level II was installed on the unit in May 1991 and tests were completed in September 1991. The average full-load NO_X emission level was 0.39 lb/10^6 Btu, corresponding to a NO_X reduction of 37 percent. Short-term, full-load tests showed the same NO_X emissions level.

The short-term tests showed that NO_X reduction was extremely sensitive to the SOFA damper opening position, with NO_X levels going from 400 ppm with closed dampers to 250 ppm for fully open dampers. Furthermore, the NO_X level was found to be not only sensitive to the SOFA damper opening, but also to the order of opening of the three SOFA dampers. Opening all three dampers uniformly resulted in lower NO_X than opening the lower damper first, followed by the middle damper and then the top damper.

Long-term NO_X emissions were relatively constant over the load range of 100 to 200 MWe, varying from 37-percent reduction at 180 MWe to 32-percent reduction at 100 MWe. However, NO_X emissions increased significantly at lower loads, reaching zero reduction at 50 MWe. This decreased effectiveness at low loads should not be a serious problem for base-load units, but could significantly impact NO_X emissions from intermediate-load and peaking units.

CO emissions remained at baseline levels (20 ppm) when the oxygen level was above 4.0 percent. However, below 4.0-percent oxygen, CO was extremely sensitive to the oxygen level, exceeding 100 ppm below 3.2-percent oxygen. The LOI of the fly ash varied from 3.8 to 5.4 percent over the load range from 115 to 200 MWe, about the same as the baseline values. However, coal fineness during LNCFS^{TM} Level II operation was somewhat better than during baseline testing.

Furnace slagging decreased from medium during baseline to low during LNCFS^{TM} Level II testing, but convection pass fouling increased. This resulted in decreased wall-blower operating frequency but increased back-pass soot-blower operating frequency. The net result was no significant change in overall surface cleaning requirements from the offset air, but improved boiler operations. This is because slagging is more difficult to remove than convection pass fouling, and because slagging often causes boiler tube failures. Operation of the ESPs was not affected, and steam outlet temperatures were similar to baseline throughout the load range.

II.D.3 Results of LNBFS Testing

Only a limited number of short-term tests were conducted with LNBFS, and no long-term tests were run. It was felt that the cost advantage of LNBFS over LNCFS™ Level II was too small to result in anything but a limited market for LNBFS, and that project funds could be better spent testing the LNCFS™ technologies. The short-term tests on LNBFS showed 30 to 32 percent NO_X reduction. Because the small amount of testing conducted does not justify drawing definitive conclusions, LNBFS is not discussed further in this report.

II.D.4 Results of LNCFS™ Level III Testing

The Level II configuration was converted to LNCFS™ Level III during a 2-week outage in November 1991 by installing close-coupled OFA nozzles in the top of the main windbox. LNCFS™ Level III testing was completed in April 1992. Full-load NO_X emissions averaged 0.34 lb/10^6 Btu, which corresponds to a reduction of 45 percent from baseline. Within the range of 100 to 180 MWe, NO_X levels were relatively constant, increasing only to 0.38 lb/10^6 Btu at 100 MWe. However, long-term NO_X emissions at low loads exhibited the same behavior as in LNCFS™ Level II testing. Below 70 MWe, NO_X emissions were at baseline levels (0.6 lb/10^6 Btu).

Short-term NO_X emissions at low load did not increase as much as the long-term NO_X emissions. At 70 MWe, short-term NO_X emissions increased to 0.4 lb/10^6 Btu from 0.34 lb/10^6 Btu at full load. This short-term testing indicated that NO_X emissions at low loads could be reduced below levels measured in the long-term tests, but perhaps with an adverse effect on steam outlet temperature and unit heat rate.

Results showed that a somewhat higher oxygen level was necessary with LNCFS™ Level III to maintain CO at an acceptable level. LOI at full load was 5.9 percent, about one percentage point higher than for baseline conditions; however, one contributing factor may have been the poorer coal fineness during the LNCFS™ Level III testing. Subsequent studies showed a strong effect of coal fineness on LOI, and it is probable that all of the increase in LOI during LNCFS™ Level III testing can be attributed to this effect.

As with LNCFS™ Level II, furnace slagging was reduced, while backpass fouling was increased compared to baseline conditions. ESP operation was not significantly impacted by LNCFS™ III operation. System operation was more sensitive to changes in operating parameters than under baseline conditions. Load transitions, which required bringing mills in and out of service, resulted in spikes of CO and NO_X. The need to keep oxygen at a higher level (4.0 percent instead of 3.2 percent used in the baseline testing) limited the flexibility of the operators being able to increase oxygen before load transitions, which would have avoided these CO and NO_X increases.

II.D.5 Results of LNCFS™ Level I Testing

As indicated above, the first retrofit consisted of adding SOFA and replacing the burners and nozzles on the boiler. In the second retrofit, the top coal and air nozzles were exchanged. Since LNCFS™ Level I does not include SOFA, LNCFS™ Level I was simulated by closing the SOFA dampers of the Level III system. The term "simulated" is used to indicate that the system tested was not identical to a typical installation of a Level I. The primary difference was that a small amount of air leakage (an average 4.4 percent of the total air flow at full load) was permitted through the SOFA ports. Some flow through the SOFA system was necessary to keep the SOFA nozzles from overheating during boiler operation.

At full load, this air leakage amounted to 4.4 percent of the total air flow into the boiler, but this was reduced significantly at loads below 140 MWe. Because this air leakage through the SOFA system supplies additional OFA, it reduces NO_X emission levels further than for a normal Level I installation. Therefore, measured NO_X emissions were corrected for SOFA air leakage, based on SOFA air flow measurements. Thus, emissions should be representative of results from a more typical installation.

Testing of the Level I system was completed in December 1992. The average long-term NO_X emissions level over the load range of 100 to 180 MWe was 0.39 lb/10^6 Btu at 3.2 percent oxygen. This represents a NO_X emission reduction of 37 percent compared to baseline operations. There were insufficient data to draw a conclusion regarding NO_X reduction at lower loads, but by analogy with Levels II and III results, NO_X emissions are expected to increase as load is reduced below 100 MWe. Average short-term NO_X emissions at full load were 0.39 lb/10^6 Btu, about the same as during the long-term testing.

The average flue gas oxygen level at full load was 3.2 percent, 0.5 percent lower than under baseline conditions. During LNCFS™ Level I testing, the boiler operated as low as 2.5 percent oxygen without any increase in CO level. This is in contrast to baseline conditions, where 3.2 percent was the minimum level of oxygen required to maintain a CO level below 100 ppm. LOI at 4.6 percent oxygen was similar to baseline conditions.

At full load, the superheat outlet temperature decreased about 5 to 10 °F, but at reduced loads, both the superheat outlet and reheat outlet temperatures decreased up to 30 °F below baseline conditions. LNCFS™ Level I operation did not significantly affect either operation of the ESP or air toxics. The medium amount of furnace slagging was similar to baseline conditions.

II.D.6 Performance Summary

The results discussed above are summarized in Table 3 and Figure 3.

Table 3. Performance Summary of LNCFS™ Technologies

Performance Measure	Technology			
	Baseline	LNCFS™ I	LNCFS™ II	LNCFS™ III
NO_X at Full Load, lb/10^6 Btu	0.63	0.39	0.39	0.34
NO_X Reduction, %	---	37	37	45
CO at Full Load, ppm	10	12	22	33
Oxygen at Full Load, ppm	3.7	3.2	4.5	4.3
LOI at Full Load, % (% oxygen)	4.8 (4.0)	4.6 (3.9)	4.2 (5.3)	5.9 (4.7)
Steam Outlet Conditions	OK at full load; low temperatures at low loads	full load: 5-10 °F lower than base-line; low loads: 10-30 °F lower	same as baseline	OK at 160-200 MWe; 15-35 °F lower at 80 MWe
Furnace Slagging	Medium	Medium	Reduced	Reduced
Backpass Fouling	Medium	Medium	Increased	Increased
Operating Flexibility	Normal	Same as baseline	More care required at low loads[a]	More difficult to operate than other systems[b]

[a] Need to watch windbox pressure drop and flame stability
[b] Sensitive to operating changes

II.E Environmental Performance

All three levels of LNCFS™ technology successfully lowered NO_X emission levels at full load. LNCFS™ Levels I and II averaged 37 percent reduction, while LNCFS™ Level III averaged 45 percent reduction. As the load was reduced, NO_X emission reduction remained relatively constant, down to a load of about 100 MWe (about 50 percent of rated capacity). As load was further reduced, however, NO_X emissions rapidly increased, reaching baseline levels at 50 to 70 MWe.

In all cases, it was possible to keep CO concentration below 100 ppm. However, it was sometimes necessary to run at higher oxygen levels than the level used during baseline conditions. At the same coal fineness, the fly ash LOI in the LNCFS™ system was similar to baseline levels. However, coal fineness was found to significantly effect LOI; it should be possible to reduce LOI by increasing coal fineness.

The different LNCFS™ system configurations showed there was little or no impact on air toxics, regardless of configuration.

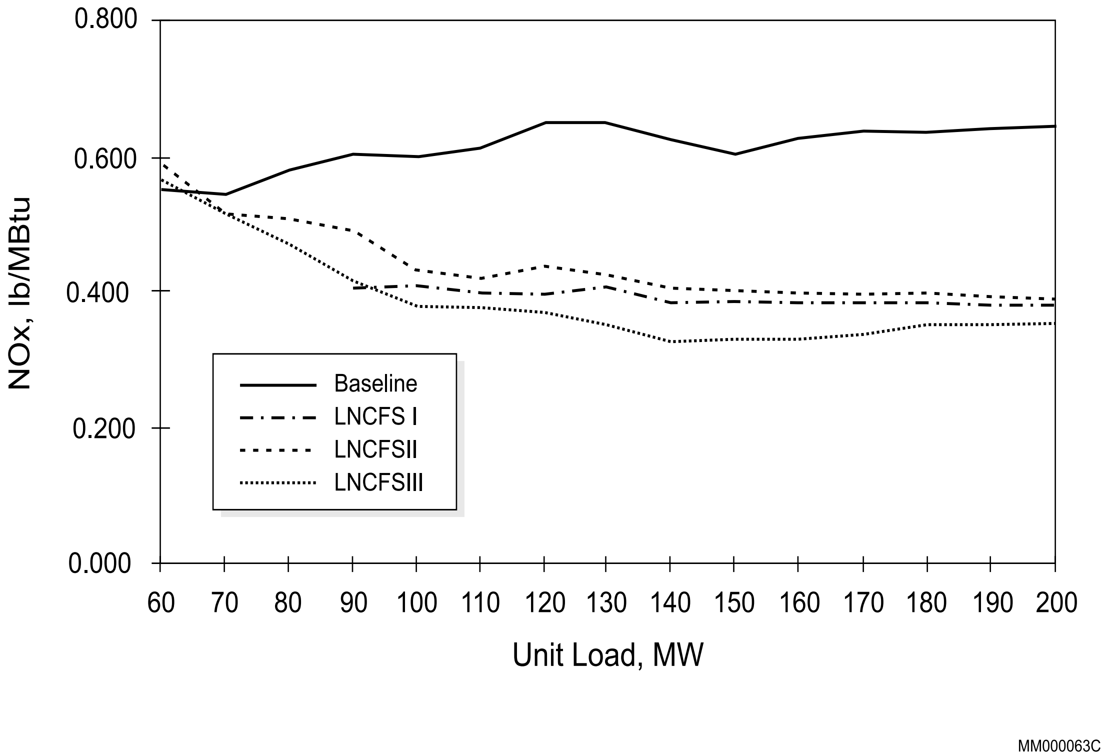

Figure 3. Comparison of Baseline and LNCFS™ I, II, and III Long-Term NO_X Emissions

II.F Post Clean Coal Demonstration Achievements

Following completion of the CCT demonstration, Gulf Power Company has continued to operate the Plant Lansing Smith Unit 2 in the LNCFS™ Level III configuration.

III Demonstrated Operating Capabilities

III.A Size of Demonstration Unit

Plant Lansing Smith, located in Lynn Haven, FL, is owned by Gulf Power Company. Unit No. 2 is a T-fired boiler, commissioned in 1967, which burns Eastern bituminous coal. It is rated at 180 MWe, but is capable of producing 200 MWe. The boiler is a Combustion Engineering, Inc. radiant reheat, natural circulation, steam generator, with five elevations of burners fed by five ABB/CE RPS 623 mills. Unit No. 2 was originally designed for pressurized furnace operation, but was converted to balanced draft operation in 1976.

Both hot- and cold-side ESPs are present, with enough capacity to be unaffected by the minor changes in flue gas volume or fly ash loading that results from the installation of the LNCFS™ system. The unit is equipped with Ljungstrom air preheaters and two forced-draft fans.

Because it was originally designed to burn more than one type of coal, the unit has a relatively large plan area, windbox height, and furnace height. In particular, the heat release rate (net heat input/plan area) of 1.65×10^6 Btu/hr ft^2 is at the low end of the range for T-fired units, which are typically 1.6-2.2×10^6 Btu/hr ft^2.

The coal burned during the test period was a medium-to-high reactivity eastern bituminous coal with 35 to 36 percent volatile matter, 46 to 47 percent fixed carbon, 8 to 9 percent ash, 9 percent moisture, 2.8 percent sulfur, and 1.4 percent nitrogen.

III.B Demonstrated Performance Level

Based on the results demonstrated in this project, estimates have been made of the annual average NO_X emission levels achievable at various dispatch scenarios by a T-fired boiler on which the LNCFS™ system is installed. The results for base-load, intermediate-load, and peaking plants are listed in Table 4.

The CO and oxygen contents of the flue gas, the LOI of the fly ash, and steam temperatures affect boiler efficiency, turbine net heat rate, and auxiliary power requirements, which in turn determine unit net heat rate. The LNCFS™ Level I system decreased the unit net heat rate from 9,995 to 9,986 Btu/kWhr; LNCFS™ Level II increased the net heat rate to 10,031 Btu/kWhr; and the LNCFS™ Level III system had a net heat rate of 10,013 Btu/kWhr. These correspond to changes in efficiency of +0.09 percent, -0.36 percent, and -0.18 percent, respectively.

Table 4. NO_X Performance Levels for LNCFS™ Technologies

Boiler Duty Cycle	Technology			
	Baseline	LNCFS™ I	LNCFS™ II	LNCFS™ III
Base Load				
Average NO_X, lb/10^6 Btu	0.62	0.39	0.41	0.36
Average Reduction, %	---	39	39	42
Intermediate Load				
Average NO_X, lb/10^6 Btu	0.62	0.39	0.41	0.34
Average Reduction, %	---	39	36	45
Peaking				
Average NO_X, lb/10^6 Btu	0.59	0.38	0.47	0.43
Average Reduction, %	---	36	20	28

III.C Commercialization of the Technology

This CCT project represents a successful commercial demonstration of the LNCFS™ technology. The unit on which the LNCFS™ system was demonstrated was a commercial boiler, operating under real-world dispatch conditions. NO_X emission reductions in the range of 35 to 50 percent were achieved, depending on the variation of the LNCFS™ system being used and the boiler operating conditions. With proper tuning and adjustment, the LNCFS™ system is applicable to a wide range of T-fired boilers.

Following completion of the CCT demonstration project, Gulf Power Company has continued to use the LNCFS™ Level III technology on Smith No. 2 unit. This continued operation is an endorsement of the technology and confirms its commercial viability and effectiveness.

The providers of the low-NO_X burner technology for this project now have installed over 130 systems on operating boilers, representing over 42,000 MWe of capacity.

The Smith No. 2 unit is not entirely typical of T-fired units. Therefore, some further investigation would provide additional understanding of the technology:

- ***Effect of Heat Release Rate.*** Smith No. 2 is at the lower end of the range for heat release rate: 1.65×10^6 Btu/hr ft^2 is low compared to a typical range of $1.6\text{-}2.2\times10^6$ Btu/hr ft^2 for most pre-New Source Performance Standards (NSPS) T-fired boilers. Information from units with higher heat release rates would indicate the significance of this variable.

- ***Windbox Height.*** The windbox in Smith No. 2 is taller than average and allowed for a 20-percent larger than normal CCOFA system. Data from other units would indicate whether windbox height significantly impacts performance.

- ***Coal Reactivity.*** The reactivity of the coal burned at Plant Smith is high compared to most eastern bituminous coals and may show less impact on LOI than low-reactivity Eastern bituminous coals. Data from other coals would indicate whether coal reactivity has a significant effect on performance.

Although these differences may require some modification to the LNCFS™ technology as it is applied to other boilers, the fact that LNCFS™ technology is already being widely used indicates that there is no fundamental barrier to using it. This indicates that the LNCFS™ system has the potential to be a major contributor to NO_X emission reduction.

IV Market Analysis

IV.A Potential Markets

LNCFS™ technology is potentially applicable to a wide range of T-fired utility and industrial boilers throughout the United States and abroad. There are nearly 600 U.S. pulverized coal T-fired utility units that range in generating capacity from 25 MWe to 950 MWe. A wide range of coals, from low-volatile bituminous through lignite, are being fired in these units. LNCFS™ technology can be used in retrofit, as well as new, boiler applications. An advantage is that boiler operation with these in-furnace technologies does not require intensive retraining of the operating staff.

IV.B Economic Assessment for Industrial Boiler Application

The following discussion on costs is only for retrofit situations. For new installations, costs should be somewhat less. The economic impact of retrofitting LNCFS™ technology to a boiler consists of capital costs, changes in operating and maintenance (O&M) costs (both fuel and nonfuel related), and lost revenue caused by unit outage during the retrofit. These issues are addressed below.

Estimated capital costs for installation of the LNCFS™ system on T-fired boilers are shown in Table 5.

Table 5. Estimated Capital Costs to Install LNCFS™ System

LNCFS™ Technology Level	Estimated Capital Costs
LNCFS™ Level I	$3 to $15/kW
LNCFS™ Level II	$10 to $25/kW
LNCFS™ Level III	$15 to $25/kW

Because of the nature of the technology, there are essentially no non-fuel-related operating costs. No reagents are involved, no additional operators are required, and maintenance costs should not change appreciably. The main change in operating cost is caused by changes in fuel costs associated with the small changes in unit efficiency. Various factors, such as changes in CO, oxygen, and LOI levels and decreased steam temperatures, are responsible for the efficiency changes. For a 180-MWe, base-load unit with a 65 percent operating factor and a $\$2/10^6$ Btu coal cost, yearly changes in operating costs range from a $18,450 decrease for LNCFS™ Level I, to a $36,900 increase for LNCFS™ Level III, to a $73,800 increase for LNCFS™ Level II. Costs for NO_X removal are estimated to be about $100/ton for LNCFS™ Level I, $450/ton for LNCFS™ Level II, and $400/ton for LNCFS™ Level III (see Table 6).

Table 6. Economics of LNCFS™ Technologies

	Baseline	LNCFS™ I	LNCFS™ II	LNCFS™ III
Average NO_X, lb/10^6 Btu	0.63	0.39	0.39	0.34
NO_X Reduction, %	---	37	37	45
NO_X Reduction, ton/yr	---	1,160	1,160	1,400
Net Heat Rate, Btu/kWh	9,995	9,986	10,031	10,013
Change in O&M Cost, $/yr	---	(18,450)	73,800	36,900
Capital Cost, $ million	---	1.44	3.06	3.60
Cost Effectiveness, $/ton NO_X Removed[a]	---	103	444	400

[a] Based on a levelization factor of 0.144 and an equipment life of 15 yr

Because the unit changes required to install LNCFS™ technology are relatively small and some of the work can be done before the unit is shut down, in most cases it should be possible to install LNCFS™ system during a scheduled shutdown. Therefore, lost income caused by downtime for technology installation should be minimal.

Because it achieves only the same NO_X reduction as LNCFS™ Level I at a higher cost, LNCFS™ Level II is not likely to be the technology of choice in most cases. LNCFS™ Level III may be chosen in cases where higher NO_X reductions are required than can be obtained with LNCFS™ Level I, although Level III was somewhat more difficult to control than Level I on the demonstration boiler.

V Conclusions

1. LNCFS™ technologies were successfully retrofitted to a T-fired boiler, and successful demonstration was achieved. All goals were met in the demonstration project, except that the NO_X reductions actually achieved were slightly less than the anticipated 50 percent reduction. In the load range of 50 to 100 percent capacity, NO_X removal ranged from 37 percent for Levels I and II to 45 percent for Level III.

2. Operation of units equipped with LNCFS™ showed relatively little impact on boiler performance criteria, such as CO level, LOI, furnace slagging, and ESP operations. In some cases, however, slightly higher oxygen levels were required to maintain target CO levels.

3. Operating units equipped with LNCFS™ technologies did not increase air toxics.

4. Costs for NO_X removal with the LNCFS™ system range from $100/ton for LNCFS™ Level I, through $400/ton for LNCFS™ Level III, to $450/ton for LNCFS™ Level II.

5. Because of higher costs at the same NO_X reduction, LNCFS™ Level II will probably not be the technology of choice in many cases.

6. The effectiveness of the LNCFS™ system decreases with decreasing load. This should not be a problem for base-load plants, but could cause difficulties for peaking plants. Further tuning and optimization may improve NO_X at low loads.

7. The LNCFS™ technology could make a significant contribution to reducing NO_X emissions from T-fired boilers.

VI Abbreviations

ABB/CE	ABB C-E Services Inc.
BACT	best available control technology
CAAA	Clean Air Act Amendments of 1990
CCOFA	close-coupled overfire air
CCT	(DOE) Clean Coal Technology Program
CEM	continuous emission monitoring (system)
CO	carbon monoxide
CO_2	carbon dioxide
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPRI	formerly the Electric Power Research Institute
ESP	electrostatic precipitator
kW	kilowatt
LNB	low NO_X burner
LNBFS	Low NO_X Bulk Furnace Staging
LNCFS™	Low NO_X Concentric Firing System
LOI	loss on ignition
MWe	megawatt electric
NAAQS	National Ambient Air Quality Standards
NO_2	nitrogen dioxide
NO_X	nitrogen oxides
NSPS	New Source Performance Standards
O&M	operating and maintenance (costs)
OFA	overfire air
RACT	reasonably available control technology
SCR	selective catalytic reduction
SCS	Southern Company Services
SIP	State Implementation Plan
SO_2	sulfur dioxide
SOFA	separated overfire air
T-fired	tangentially fired
VOCs	volatile organic compounds

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